Metamorphic evolution and tectonic implications of the metamorphic rock series in the Xilinhot-Linxi area, Inner Mongolia

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2011

document version
Publisher's PDF, also known as Version of record

Abstract

The Central Asian Orogenic Belt (CAOB) is a large accretionary orogen that separates the Siberia Craton to the North from the Tarim and North China Cratons to the South. The Xilinhot-Linxi area is located in the Solonker suture zone between the Siberia Craton and the North China Craton, which is the eastern section of the CAOB and records the termination of convergence in the CAOB. Subduction of oceanic lithosphere and accretion of different microcontinents resulted in closure of the Paleo-Asian Ocean between the Siberia and North China Cratons in the area. The evolution of the CAOB is subject to discussion; in particular the tectonic style, the position of the suture, the timing of final suturing and the process of collision. In contrast to Circum-Pacific-type accretionary orogenic belts formed by oceanic subduction below a continent, and Alpine-Himalayan-type orogenic belts formed by continent-continent collision, the CAOB formed due to accretion of small Paleozoic microcontinents separated by suture belts.

The Xilin Gol Complex and the Shuangjing Complex are typical metamorphic rock series in research area and contain middle-low grade regional metamorphic rocks. To reconstruct the tectonic framework of the CAOB in the research area and unravel the process of the closure of the Paleo-Asian Ocean, we chose the Xilin Gol Complex and the Shuangjing Complex as main research targets, together with some dynamic metamorphic rocks and intrusives in the area, to study their mineralogy, petrology, geochemistry and geochronology. The results are summarized below:

1. The protolith of the biotite-plagioclase gneiss from the Xilin Gol Complex is a sedimentary rock. Its source ages are older than 800 Ma and mainly cluster around 1150-900 Ma. The protolith was deposited at the southern active continental margin of the Siberia Craton during assembly of the Rodinia supercontinent. This resolves the debate regarding the age of the Xilin Gol Complex by conclusively showing that it is a Middle to Late Proterozoic terrane. The Xilin Gol Complex recorded the Middle to Late Proterozoic amalgamation of Rodinia at the southern margin of the Siberia Craton (Chapter 3).

2. The Xilin Gol Complex is a Precambrian basement unit at the southern margin of the South Mongolia microcontinent that separated from the southern margin of the Siberia Craton during the breakup of Rodinia. The complex underwent partial melting and migmatization at 452 ± 5 Ma in response to north-dipping oceanic subduction in Sonidzuoqi-Xilinhot area. Subduction of the Paleo-Asian Ocean started around 490 ± 8 Ma (Chen et al., 2001) and lasted at least until 440 ± 4 Ma (Zhang et al., 2004). Many

new magmatic materials formed at this time and preserved in the complex, reflecting the presence of a continental marginal arc. The Xilin Gol Complex underwent strong alteration and recorded the Early Paleozoic oceanic subduction and accretion of the Central Asian Orogenic Belt along the Xilinhot-Sonidzuoqi north-dipping thrust belt. It was not a block that had rifted off the margin of Gondwana, but recorded the accretion of the long-lived, single arc at the southern margin of the South Mongolia microcontinent. Continued subduction of the oceanic crust finally resulted in collision between the accretion zones of the North China Craton and the South Mongolia microcontinent. The continental crust in the area then entered a tectonic cycle of uplift - weathering - erosion - sedimentation (Chapter 3).

3. After Early Paleozoic oceanic subduction, transient extension occurred from 320 Ma (Chapter 4) until 280 Ma (Zhang et al., 2008) along the line Sonidzuoqi-Xilinhot. Extension induced widespread magmatic activity and thinning of the overriding continental crust, including the Xilin Gol Complex, resulting in the formation of an oceanic basin at the southern margin of the complex. This stage of extension may reflect collapse after the collision between the oceanic and continental arcs. The protolith of a plagioclase-amphibolite exposed in the Xilin Gol Complex is a basic magma that intruded into the Xilin Gol Complex at 318 ± 5 Ma as determined by LA-ICPMS U-Pb zircon dating. A biotite $^{40}Ar/^{39}Ar$ age 312.2 ± 1.5 Ma from a biotite-plagioclase gneiss in Xilin Gol Complex also recorded this thermal event. Amphibolite facies metamorphism at a pressure of 0.31-0.39 GPa and temperature of 620-660°C occurred at 263.4 ± 1.4 Ma, as indicated by a hornblende $^{40}Ar/^{39}Ar$ age. The magma of the basic intrusion was not a primary magma but experienced crystal fractionation. Slab-derived fluids admixed into the magma source, which formed during Early Paleozoic oceanic subduction along the Sonidzuoqi-Xilinhot north-dipping subduction zone. Final collision of the Solonker suture zone occurred from 265 to 228 Ma. Closure of the marginal ocean basins around the Xilin Gol Complex induced amphibolite facies metamorphism at the base of the Xilin Gol Complex (Chapter 4).

4. An Early Paleozoic subduction-accretion zone and a Late Paleozoic to Early Triassic subduction-accretion zone were distinguished from north to south at the southern edge of the South Mongolia microcontinent. They recorded accretion at this active margin and contraction of the Paleo-Asian Ocean from Ordovician to Triassic times. The Early Paleozoic subduction-accretion zone is made up of two branches. The northern branch was formed by the northward subduction of the Paleo-Asian Oceanic plate beneath the South Mongolia microcontinent at ~452 Ma, which induced the extensive melting of overriding continental crust. Continued subduction led to arc-continent collision at the

southern margin of the South Mongolia microcontinent, reflected by magmatic activity at 416 ± 3 Ma in the southern branch of the Early Paleozoic subduction-accretion zone. After Early Paleozoic accretion of the South Mongolia microcontinent to the North China Craton, transient extension along the southern edge of the South Mongolia microcontinent caused widespread magmatic activity at 316 ± 2 to 302 ± 2 Ma and led to the formation of oceanic basins. Late Paleozoic-Early Triassic north-dipping subduction facilitated closure of these oceanic basins and final suturing of the CAOB during the Late Permian to Middle Triassic by further accretion to the South Mongolia microcontinent. This subduction caused uplift, thickening, fast erosion and deposition of the overriding continental crust, which led to the formation of siltstones composed of arc volcanic and plutonic materials with crystallization ages of 299 ± 3 to 267 ± 3 Ma, and some intrusions at 274 ± 2 Ma due to melting of continental crust along the northern margin of the Solonker suture zone. Accretion and collision peaked at ~260 Ma, leading to final collision and suturing in the Central Asian Orogenic Belt. The Xilinhot-Sonidzuoqi area entered a post-orogenic regime from 222 ± 4 Ma (Chapter 5).

5. The Xilin Gol Complex, together with the basic intrusions in it, recorded the progressive accretion of a single, long-lived subduction system at the southern edge of the South Mongolia microcontinent from Late Proterozoic (~800 Ma) to Middle Triassic (~228 Ma) times (Chapters 3, 4 and 5).

6. The Shuangjing Complex is mainly composed of granitic gneiss and schists and is situated along the northern margin of the North China Craton. The schists in the complex were formed during prograde greenschist facies metamorphism. Their protolith is a volcanic-sedimentary rock series, whose formation is related to an arc/forearc basin during the Late Carboniferous-Early Triassic in the Linxi area, central Inner Mongolia. The volcanic parts of the schist belong to a calc-alkaline series with large volumes of intermediate members and subordinate acidic members. The volcanism was induced by subduction-related magmatism resulting from mantle metasomatism and erupted in a continental marginal arc. The sedimentary parts of the schist reveal characteristics of various depositional sequences including shelf, slope and deep sea sediments. In the Linxi area, final closure of the Paleo-Asian Ocean in the Late Carboniferous was followed by closure of the arc/forearc basin, which induced subduction of oceanic crust and the leading continental margin in the Late Permian-Early Triassic. The closure of multiple oceanic basins led to two contrasting hypotheses regarding the timing of final suturing in the Solonker suture zone. Final suturing of the Solonker suture zone finished in the Late Permian to Early Triassic. (Chapter 6).

7. The magma of the granitic gneisses in the Shuangjing Complex arose from

melting of thickened continental crust during the collision between the North China Craton and the South Mongolia microcontinent. The granite was initially emplaced along the Xar Moron fault belt at 272 ± 2 Ma and, in terms of volume, dominantly at 265 ± 2 Ma, implying that final collision of the Central Asian Orogenic Belt started before 272 ± 2 Ma. Magmatic activity lasted about 10 Ma. There is a concentration of crustal xenoliths at the edge of the marginal facies of the granite. The granitic domains between the crustal xenoliths crystallized at 270 ± 1 Ma and therefore derive from the granitic magma. The presence of Paleoproterozoic intermediate magmatic rocks below the schist in Linxi area is suggested by detrital zircon ages of 2190 ± 8 to 1804 ± 25 Ma from the xenoliths. A xenolith zircon core age of 3377 ± 7 Ma indicates Paleoarchean basement may also be present in the source area. Prodigious amounts of heat from the main intrusion of the Fangkuangzi granite at 265 ± 2 Ma induced partial melting of the crustal xenoliths, resulting in localized formation of new granitic melts at 263 ± 2 Ma. Continuous collision of the CAOB until 231 ± 2 Ma induced metamorphic recrystallization of zircon in the Shuangjing Complex and the ENE-striking penetrative foliation in Linxi area. The Paleoproterozoic basement in the Linxi area is thought to have been a part of the original North China Craton that was separated from the northern margin of the craton during the breakup of the Rodinia supercontinent. The resulting Shuangjing microcontinent is exposed in the Solonker suture zone (Chapter 7).

8. The Xilin Gol Complex occurs at the northern margin of the Solonker suture zone and the Shuangjing Complex marks its southern margin. The northern Sonidzuoqi-Xilinhot area entered an ocean-continent subduction setting from 490 Ma. It underwent extensive partial melting or migmatization at 452 Ma in response to north-dipping subduction of the Paleo-Asian Ocean below the South Mongolia microcontinent and then experienced transient extension during 320-280 Ma. Final collision started after 275 Ma and continued from 263 to 228 Ma because of the closure of the marginal oceanic basins. Meanwhile, the Linxi-Ondor Sum area along the southern subduction zone underwent extensive partial melting at 451 Ma, experienced transient extension from 300 to 285 Ma, and became collisional from 272 to 231 Ma. The two subduction zones have similar tectonic evolutions, suggesting bilateral subduction and accretion of the Paleo-Asian Ocean, towards the North at the southern margin of the South Mongolia microcontinent and to the South at the northern margin of the North China Craton (Chapters 3, 4, 5, 6 and 7).

9. Suturing of the Solonker suture resulted in the amalgamation of the North China Craton with several microcontinents to its north, including the South Mongolia microcontinent, to form the Mongol-North China block. The Mongol-Okhotsk Ocean was

a NE-oriented branch of the Paleo-Pacific Ocean between the Siberia Craton and the Mongol-North China block. The closure of the Mongol-Okhotsk Ocean in NE Mongolia in the Early Jurassic induced continent-continent collision at 188.7 ± 1.4 Ma. After collision, the research area underwent post-orogenic extension, while the Paleo-Pacific plate simultaneously subducted beneath the North China Craton. This combination of post-orogenic extension and the subduction led to several switches between compression and extension in the Jurassic in the eastern North China. After a change in the subduction direction of the Paleo-Pacific plate in the Late Jurassic, the tectonic environment in northeastern China finally became extensional from 160 to 100 Ma and the region joined the West-Pacific orogenic domain (Chapter 8).

10. On the basis of this research on the metamorphic series in the Xilinhot-Linxi area the tectonic evolution of the eastern Central Asian Orogenic Belt is divided into four stages: Precambrian basement evolution, Early Paleozoic arc-continent convergence, Late Paleozoic - Early Triassic opening and closure of a marginal ocean basin and Mesozoic active continental margin development (Chapter 9).